Future Prospects at e^+e^- Machines

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1 Introduction

This review will present the physics prospects for physics at e^+e^- machines running near the $\Upsilon(4S)$ as well as at the charm and tau thresholds. I will briefly review the plans for BES III, which operates near the charm threshold at IHEP's BEPC machine in Bejing and the status of the Super Charm/Tau Factory proposed for the Budker Institute for Nuclear Physics (BINP) in Novosibirsk.

At the time of this conference the particle physics community was looking forward to having two next generation high luminosity e^+e^- machines running at or near the $\Upsilon(4S)$ operating by the end of the decade: the Belle II experiment at the SuperKEKB machine in Japan and the SuperB experiment at the recently created Cabibbo Laboratory in Italy. Before the end of 2012, however, the unfortunate fiscal difficulties facing many European countries forced the Italian government to cancel SuperB. Nonetheless, I will discuss both of these projects in this review.

2 BES III Datasets and Future Plans

In 2009 BES III collected 106 million events on the $\psi(2S)$ resonance and 225 million at the J/ψ resonance, where each represents a sample that is four times larger than the samples collected by CLEO-c and BES II, respectively. The program in 2010 and 2011 focused on running at the $\psi(3770)$ and $\psi(4040)$ where a total of 2700 pb^{-1} and 470 pb^{-1} of data were collected, respectively. The physics running in 2012 saw the accumulation of data at tau-pair threshold to be used in a new precision tau mass measurement, 400 million events at the $\psi(2S)$, one billion J/ψ events, and an energy scan to measure R, the ratio of the total hadronic to muon-pair cross sections.

Looking to the future, BES III will collect data at centre-of-mass energies of 4260 MeV and 4360 MeV in order to conduct spectroscopic studies of the "XYZ" states and they will also continue the R scan. Plans for 2014 have the machine running at 4170 MeV in order to collect roughly 2.4 fb^{-1} of data to study the D_s. There are no firm plans for the program beyond 2014, although the collaboration

would like to collect 10 fb^{-1} of $\psi(3770)$ data. BES III is scheduled to collect data for another eight to ten years.

3 BINP Super Charm/Tau Factory

The physics goals of the Super Charm/Tau Factory being planned for Novosibirsk [1] includes:

- High statistics spectroscopy and searches for exotics
  - Charm spectroscopy
  - Spectroscopy of the highly excited charmonium states (complementary to bottomonium)
  - Light hadron spectroscopy in charmonium decays
- Precision charm physics
  - Precision charm CKM (strong phases, f_D, f_{D_s},form factors, etc)
  - Use this unique source of coherent $D^0/\overline{D^0}$ states for a variety of measurements (D^0 mixing, CPV in mixing, strong phases for γ/ψ_3 measurements at SuperB/Belle II and LHC)
- Precision τ-physics with polarized beams
  - Lepton universality, Lorentz structure of τ-decay
  - CP and T-violation in τ and Λ_C decays
  - Search for lepton-flavour-violating decays such as $\tau \to \mu\gamma$
  - Measure second class currents (with kinematical constraints at threshold)
- Two photon physics and light hadronic cross section via ISR

The machine will operate at centre-of-mass energies ranging from 1.0 to 2.5 GeV with online energy monitoring with a precision at the level of 5-10$\times 10^{-5}$ and a design peak luminosity of 10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 2 GeV. Also, the electrons are to be polarized longitudinally at the interaction point.

The collider will have two separate rings utilizing the crab waist collision scheme[1] at a single interaction point (IP) with a goal of a reaching sub-millimeter beta-y at the IP. A 2.5 GeV linac will be used to inject beam at full energy. Four super conducting wigglers will be used to help preserve damping parameters through the whole energy range in order to optimize the luminosity. Five Siberian snakes will be used to obtain the longitudinally polarized electrons, again for the whole energy range. It will use a

polarized electron source and a positron source that will have a 50 Hz top-up injection frequency.

Although the project was included in the 2012 list of the top six projects approved for further development by the Russian Governmental Commission on the Innovations and High Technologies, at this time the project is not yet approved for funding.

4 The Super B Factory Experiments: Belle II and SuperB

These facilities are designed to collide electrons and positrons at centre-of-mass energies near the Υ resonances. Most of the data will be collected at the $\Upsilon(4S)$ resonance, which is just above threshold for B-meson pair production where no fragmentation particles are produced. The luminosity is expected to be 40-100 times that of the previous generation colliders: SuperKEKB [2] has a design luminosity of $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ whereas SuperB [3] was designed for $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. These would produce 5-10$\times 10^{10}$ b, c and tau pairs corresponding to 50-75 ab^{-1}. Both machine designs have asymmetric beam energies in order to give a boost to the centre-of-mass system and thereby allow for time-dependent CP violation measurements.

4.1 Physics Program

The overall physics goal of these next generation flavour factories is to search for evidence of new physics in the flavour sector at the precision frontier [4, 5]. Included in this program are:

- tests of the CKM matrix at the 1% level and searching for non-CKM sources of CP violation in B decays
- precision searches and measurements of $B \to K^{(*)}\ell^+\ell^-$, $B \to \tau\nu$, and $B \to D^{(*)}\tau\nu$, which all use the B-recoil technique
- precision studies of the tau lepton, including searches for lepton-flavour-violating decays, measurements of g-2 and the electric dipole moment of the tau, CP violation, the CKM element $|V_{us}|$
- precision measurements of charm, including mixing and CP violation
- searches for low mass Higgs bosons predicted in theories beyond the standard model
- searches for evidence of a dark sector

- if a polarized beam is available, precision electroweak physics that includes precise and unique measurements of the neutral current vector coupling of b, charm, tau, muons and electrons

The program also includes precision QCD measurements involving $\Upsilon(5S)$, ISR radiative return and hadron spectroscopy.

The physics motivation for the e^+e^- super B factories is independent of results from the LHC: if LHC finds new physics, precision flavour input is essential to further understand those discoveries. On the other hand, if the LHC finds no evidence for new physics, the high statistics b, charm and tau samples provide a unique way to probe for new physics beyond the TeV scale.

Regarding the interplay between e^+e^- machines and LHCb: the two experiments are highly complementary[6]. LHCb will have high statistics samples of both B_s and B mesons and will produce measurements that dominate the all-charged final states. However, a super e^+e^- machine will dominate B measurements of final states with π^0 or other neutral particles, including neutrinos. The e^+e^- program also includes extensive precision studies of the tau and a number of other non-flavour physics topics.

4.2 Machines

SuperB [3, 7] was designed to achieve a luminosity of $10^{36}\mathrm{cm}^{-1}\mathrm{s}^{-1}$ by having beams cross with a large Piwinski angle (as at DAPHNE and KEKB); very low vertical and horizontal beta functions (as designed for the ILC); low horizontal and vertical emittances (as used in light sources); and ampere-level beam currents (as in PEP-II and KEKB). For the $\Upsilon(4S)$ running, the positrons were to have an energy of 6.7 GeV and the electrons, polarized at the source, an energy of 4.2 GeV.

SuperKEKB [2] is designed for a luminosity of $8{\times}10^{36}\mathrm{cm}^{-1}\mathrm{s}^{-1}$ with a large half crossing angle of 41.5 mrad; horizontal emittances of 3.2 nm for the low energy (LER) and 5.0 nm high energy (HER) beam; beta functions at the IP of β_x^*/β_y^* equal to 32 mm/0.27 mm (25 mm/0.31 mm) for the LER (HER); currents of 3.6 A (2.6 A) for the LER (HER); and a beam-beam tune shift of 0.0886 (0.0830) for the LER (HER). The positron beam is 4 GeV and electron beam 7 GeV at SuperKEKB and the machine does not have a polarized beam in its baseline design. The beams are injected into their respective rings with low emittance: the electrons are produced using a low emittance gun, whereas the positron beam uses a damping ring to ensure low emmittance.

4.3 Detectors

The SuperB detector [8] at the Cabibbo Lab was to reuse many components from BaBar: the magnet, DIRC bars and barrel CsI(Tl) calorimeter. The new components

were to include: a new silicon detector with an additional 'Layer 0' around a smaller beam pipe; a new small cell drift chamber with the possibility of incorporating cluster counting in order to improve particle identification; a new way to read out the DIRC that does not project through a water tank as was done in BaBar; a new forward calorimeter; and a new muon detection system. SuperB was entertaining the possibility of a forward particle identification system and had plans to incorporate a backward calorimeter into the detector.

The Belle II detector [2] reuses the magnet and barrel and endcap calorimeters from Belle. It will have a new vertex detector with four layer double-sided silicon and two DEPFET pixel layers close to the beam; a small cell, larger radius drift chamber; a barrel particle identification system employing a novel technology, called the Time of Propagation (TOP) system, which uses a quartz radiator and incorporates a combination of Cherenkov radiation and propogation times to produce particle identification information [9]; and a new K_L-muon detector that will use scintillators read out with a multi-pixel photon counter (MPPC). In an upgrade, the CsI(Tl) endcap calorimeter crystals will be replaced with significantly faster pure CsI scintillators. The detector is scheduled to begin commissioning in 2015.

4.4 Status

Although, as mentioned, the Italian government cancelled the SuperB project at the end of 2012, the status regarding SuperKEKB is excellent. Approximately US$100 million for the machine was approved in 2009 via Japan's Very Advanced Research Support Program. Full approval by the Japanese government came in December 2010. The project was formally in the JFY2011 budget and approved by the Japanese Diet end of March 2011. Most non-Japanese funding agencies have also already allocated sizable funds for the upgrade of the detector. Construction was started in 2010 and fortunately there was little damage caused by the March 2011 earthquake - it did not introduce any delay in the project. The ground breaking ceremony was held in November 2011 and both SuperKEKB and Belle II construction is proceeding according to schedule.

5 Summary

BES III has concrete plans for an exciting physics program through 2015 and is scheduled to continue to run for another eight to ten years.

There are promising developments for a Super Charm-Tau Factory in Novosibirsk with a sizable community associated with the project, although the project is not yet approved for funding.

The super B e^+e^- flavour factories provide an extremely broad, rich, and exciting

physics program with sensitivity to new physics that is complementary to the LHC. There is flexibility in ways that such machines can achieve the high luminosity with beam currents and power comparable to current facilities. Unfortunately, the SuperB project was cancelled by the Italian government in late 2012. On the other hand, SuperKEKB received Japanese Diet approval for the complete project in 2011 and the construction on that project is proceeding well.

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